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DESIGN AND EFFECTS OF ATOMIC WEAPONS

- SWEDEN -

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FOREWORD

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[Following is a translation of an article by Torsten Magnusson in the Swedish-language periodical Kosmos, Fysiska uppsatser (Papers on Physics), Stockholm, Vol. 34, 1956, page 180-208.]

As we know, atomic energy can be derived from the heaviest and the lightest elements. This is a result of the variation within the periodic system of the cohesive energy, i.e., the energy required to split an atomic nucleus into free nucleons. The cohesive energy per nucleon is shown in Fig. 1. As can be seen it is largest for medium-weight elements and smaller for the lightest and the heaviest elements. When heavy atomic nuclei split (fission) and when light atomic nuclei units (fusion), atomic nuclei are thus formed with higher cohesive energy per nucleon than in the original nucleus, with the result that energy is released. So far it has been possible to regulate only the first process and utilize it as a source of power even if optimistic statements have been made concerning the possibilities to use also the fusion process for such a purpose. Both processes can, however, be utilized as weapons in "uranium weapons" and "hydrogen weapons".

Design of Uranium Weapons

The fission process has been treated in Kosmos Vol. 19 by S. Eklund and in Vol. 32 by G. Holte, and therefore only a short summary of certain essential facts will be given here. The splitting of the heavy atomic nuclei is brought about by these nuclei catching a neutron. But a hit by a neutron does not always create a fission. Competing processes are dispersion and absorbtion without fission as a result. The average effects of these processes depend upon which elements and which isotopes are involved and furthermore varies with the energy of the neutron.

There is a marked difference between the processes in an atomic reactor and in an atomic charge. The former is to be used in a continuous operation and must not constitute any risks for the surroundings. Great requirements are therefore made on, among other things, the materials that are part of it. An atomic charge is used only once and the requirements are therefore of another type. Here the problem is to achieve a rapidly continuing chain reaction which in a very short time, in the order of a few microseconds, extends to as large

a number of atomic nuclei as possible. It is not necessary to retard the neutrons formed through the fission, which have a mean energy of about 1 MeV, to thermal energy. No moderator will therefore exist in an atomic charge. At 1 MeV the relation between average fission and average absorbtion is large enough only for U 233, U 235, and Pu 239. We know that the two last ones have been used in atomic charges. But also U 233, which can be obtained in reactors - above all in breeders - from thorium, seems to be useful for this purpose even if this has not been clearly determined. All atomic weapons based on the fission process are usually called "uranium weapons", regardless of which fissionable material is used.

A very essential factor for utilization of atomic energy is the neutron economy. At each fission an average of 2.5 new neutrons are formed by U 235 and 3 by Pu 239. A portion of these neutrons are lost in an atomic charge to the construction material and to impurities in the fissionable material. Another portion is lost to the surroundings. What is left then causes further fissions. If more than one neutron per nuclear fission remains for this purpose, more fissions are achieved in the next "generation" and their number then grows successively for each new "generation". To achieve a high efficiency at the explosion of the atomic charge, a rapid growth in the number of fissions is sought. This means that an effort must be made to keep the absorbtion of neutrons into the construction material down and to avoid neutron absorbing impurities in the fissionable material.

The losses of neutrons to the surroundings play a very large role. At a small quantity of fissionable material these losses become so large that a chain reaction will not occur, or will cease, before any large number of nuclei have fissioned. As long as the fissionable material is kept in such small quantities it is not dangerous to handle. As the amount of the material increases, the losses become relatively smaller because they are proportionate to the surface and thus grow with the square of the radius while the amount of fissionable material grows with the cube of the radius. When a certain amount is reached, the so called critical size, an explosion occurs. If the material is of just this size, it will rapidly return to sub-critical size at the explosion. To achieve any greater efficiency an effort is made to reach a super-critical size before the explosion occurs. A considerably larger number of atomic nuclei will then be split. An effort should therefore be made to pass the critical size as rapidly as possible. An efficient method to reduce the neutron losses to the surroundings is to inclose the fissionable material in a material reflecting the neutrons back to the former. Heavy elements are suitable for this purpose and this so called tamper seems to consist of natural uranium or uranium deprived of a large portion of its content of the isotope 235.

The principle for the design of a uranium bomb is thus fairly well known. The fissionable material can from the outset be kept in two or more parts, each smaller than the critical size but together

exceeding it. Another possibility is to have the uranium assembled in such a shape that it is not critical from the outset but quickly can be made critical. An example of the principle of such a design is shown in Fig. 2 where the fissionable material first has the shape of a spherical shell. To achieve a better efficiency this shell is preferably surrounded by a tamper of heavy material. Around the tamper is then a layer of explosives and arrangements to bring it to simultaneous detonation over the whole surface. Hereby the spherical shell of fissionable material is compressed into a compact sphere. If the amount of this material is larger than the critical size, an atomic explosion will occur. It is desirable that the nuclear fission begins when the atomic charge is in its most super-critical form which occurs when the fissionable material is most compressed. Very heavy requirements are made on the design of the explosives in an atomic charge and the nuclear physical initiation must be regarded as a problem very difficult to master. In addition, the explosive and initiator events must be synchronized to one or a few microseconds.

The critical size of uranium 235 is now relatively well known, particularly through the information released in connection with the atomic energy conference in Geneva in August 1955. At a normal density and without tamper, 40 kilograms has been indicated. For an unlimited tamper it goes down to about 15 kilograms and for actually occurring thicknesses of the tamper somewhere in between. For plutonium, averaging three newly created neutrons per fission as against two and a half for U 235, the critical size is several times smaller and is in the order of 5 kilograms. An atomic charge needs to contain more than the critical size. This size, on the other hand, may be decreased through heavy compression. The above values therefore indicate the right magnitude of the minimum content of fissionable material in an atomic charge.

Although the weight of the fissionable material does not amount to more than one or a few tens of kilograms, the total weight is considerable. For the atomic bombs released in 1945 over Japan it has been given as about 4 metric tons of which the larger portion probably derived from the tamper. Now, however, atomic weapons of a considerably lower weight can be manufactured. For the light atomic weapons intended for, among other things, tactical use, the weight does not amount to more than a few hundred kilograms and at the same time the dimensions are smaller. Diamters of 21 centimeters seem fairly definitely to be a possibility and even lower values have been mentioned. Because of this, completely different means of transportation are available than for heavy atomic bombs of the Japan type. Fighter bombers, guided missiles, or torpedos can be used for this purpose and such atomic charges can also be fired by cannon. All airplanes capable of carrying bombs are thus able to carry an atomic bomb as well as a conventional high-explosive bomb.

The fissionable material in all uranium bombs must, however, exist in a quantity exceeding the critical size. In light atomic weapons this material, however, is less efficiently utilized than in heavy weapons. The development in the field of atomic weapons after the war has, however, also gone in another direction. It is now possible to manufacture uranium bombs considerably more powerful than those released over Japan. Thus President Eisenhower has announced that uranium bombs 25 times as powerful can be manufactured. Both the weight of the fissionable material in these atomic bombs and the total weight of them must, however, be considerably greater than for the light atomic weapons. Presumably they can only be transported by heavy bombers or guided missiles.

Design of Hydrogen Weapons

Hydrogen weapons are usually defined at atomic weapons in which at least a portion of the release of energy occurs through fusion, i.e. through reactions between two of the lightest atomic nuclei, whereby a somewhat heavier nucleus is formed. The average effects of these reactions are, however, very small at a normal temperature. Only at 10^7 to 10^8 degrees Centegrade do they reach such a height that there is any probability of reaction worth mentioning, and these reactions are therefore designated as thermonuclear. The relation between the fusion and dispersion averages also increases greatly with the temperature for the nuclear reactions in question. Thermonuclear reactions have been described in Kosmos, Vol. 28, by B. Pershagen.

Most discussed of these reactions are those between the heavy hydrogen isotopes deuterium and tritium.

$$\begin{aligned} D + D &\rightarrow H + T + 4.0 \text{ MeV} \\ D + D &\rightarrow He^3 + n + 3.3 \text{ MeV} \\ T + D &\rightarrow He^4 + n + 17.6 \text{ MeV} \\ T + T &\rightarrow He^4 + 2n + 11.4 \text{ MeV} \end{aligned}$$

The release of energy at the two last reactions is 2.5 and 4.5 times as large per unit of weight as at the fission process. On the other hand, a considerably larger number of nuclear reactions are required for release of the same amount of energy in the former case than in the latter case. Even other reactions between light elements may be possible, for example between Li^6 and D. To determine which reactions are the most suitable, a thorough knowledge of the average effects and their variation with the temperature is required. Published information on this subject is, however, incomplete.

The great dependence on temperature at the average effect of the T + D reaction is evident from Fig. 3. The dependence on temperature at the D + D reactions has a similar course but the average effects are in this case about a thousand times smaller. Tritium and deuterium are said to undergo fusion more rapidly than any other pair

of isotopes. The most commonly occurring concept in various articles is therfore that the hydrogen bomb is based on a reaction between these two atomic nuclei. The required high temperature can be obtained by using a uranium bomb as an "ignition cap".

The principle of function closest at hand for a hydrogen bomb is then the following. At the high temperature created through the explosion of the uranium bomb, deuterium and tritium react with each other. Then they unite, the temperature rises further, and it is then possible to make two deuterium nuclei react with each other. The heavy hydrogen is relatively easy to manufacture. Tritium, however, is complicated and difficult to manufacture. It can be obtained through radiation of the isotope Lithium 6 in an atomic reactor. Tritium as well as deuterium must, however, be compressed under heavy pressure and cooled down to a very low temperature which would require thick-walled steel containers. A hydrogen-bomb design according to the above principle therefore would be very heavy, 10 metric tons or perhaps even more.

Other methods are open, however, to make a hydrogen bomb. Instead of pure deuterium and tritium it would be possible to use stable chemical compounds of these elements whereby the heavy cover could be reduced. And it would be possible to take another step in this direction and produce the required tritium in the hydrogen bomb itself by letting it contain Li 6. Because tritium, having a half life of only 12 years, is not contained in the hydrogen bomb originally, this bomb, as well as the uranium bomb, will have an indefinite storage life.

Measurements of radioactive dust created through certain hydrogen bomb tests show that this dust consists mainly of fission products. The larger portion of the energy released by the explosion of such hydrogen bombs thus must have originated from the splitting of heavy atomic nuclei and only a smaller portion could originate from the thermonuclear reactions. The following principle for the design of a powerful hydrogen bomb can thus be made, as portrayed in Fig. 4. Innermost is a shell of fissionable material; this is the uranium bomb that is to provide the required high temperature. Outside this shell is a layer of lithium deutride and outside this a heavy layer, up to several metric tons, of natural uranium or, perhaps more probably, such uranium with a low content of Uranium 235, which is obtained in great quantities as a "waste product" at the production of fissionable material. Outermost, as with the uranium bomb, are explosives for compression of the active elements at the initiation.

A hydrogen bomb designed in this way can be said to function in three stages which, however, follow each other very quickly within the course of a few microseconds. The first stage comprises the explosion of the "igniting" uranium charge. Hereby a temperature of several tens of millions degrees Centigrade is created at the same time as a swarm of neutrons from the fissions are sent out toward the surrounding shell of lithium deutride. The second stage actually consists of two substages. When the fission neutrons hit the Li 6

nuclei, tritium and helium are formed. The average for this reaction has a very high value. The tritium nuclei formed have a great speed as a result of the energy of 3 MeV they receive at the reaction. They will thus easily hit the incoming deuterium nuclei and are able, under the prevailing conditions, to react with them according to the previously mentioned reaction. Hereby helium and neutrons are created, the latter of which receive an energy as high as 14 MeV. The third stage occurs when these neutrons hit the atomic nuclei in the surrounding uranium layer consisting, for the very greater part, of the uranium 238 isotope. The fission average for this isotope has a threshold value at the neutron energy 1.5 MeV and therefore hardly undergoes any fission at all when hit by fission neutrons from uranium 235 because their energy is at the level of about 1 MeV. But for the 14 MeV-neutrons the fission average is sufficiently high to achieve fission with a considerable probability. The heat and neutrons created by this process also go inward to the center of the hydrogen bomb and contribute to an increased yield from the thermonuclear reactions. At the hydrogen bomb test on March 1, 1954, 80 to 90 per cent of the released energy seems to have originated from this third stage according to the calculations made.

The weight of a hydrogen bomb designed in this way, with a yield a hundred times larger than for the Japan bombs, may be calculated at about one metric ton. For a bomb with another 10 times this yield, a weight of 5 to 10 metric tons must probably be assumed.

There has been much speculating about other means than a uranium bomb to achieve the required high temperature; it is actually the thereby prevailing high kinetic energy that is desirable. Primarily considered are then certain electrical phenomena such as discharges, exploding wires etc., but also shaped charges have been mentioned. We should remember that 10^8 Centigrades is the equivalent of 10 keV. Intense research concerning the various means to achieve high temperatures is conducted in several places abroad. It should be pointed out that these studies are of great interest also with consideration to the opportunities to be able to utilize thermonuclear reactions as a source of power for civilian purposes. In the fall of 1956, for example, two Russian scientists reported on extensive research they had conducted in this field. How far scientists have progressed in this field and which possibilities that exist to design hydrogen weapons based on such methods, we are unable to determine. It should be remembered though, that the Americans have announced that in the spring of 1956 they tested atomic weapon designs of a new type with a "minimum widespread fall-out hazard". We will return to this subject later.

If the problem to achieve the high temperature can be solved without resorting to a uranium charge, then it might perhaps be possible to produce relatively light hydrogen bombs which do not need to be so fantastically expensive either. The available amount of destructive

means can thus be further increased by a considerable quantity, but simultaneously with these gloomy perspectives for the future the chance is opening for civilian use of thermonuclear reactions.

For the hydrogen bombs there is no minimum critical size in the same way as with the uranium bombs. The factor determining the limit downward is the balance between produced and radiated energy, in other words the pure thermodynamic conditions. No upward limit exists and it would actually be possible to produce hydrogen bombs of any yield. Probably a limit is reached in practice, above which a further addition of active material would not cause the effective area to increase to any considerable degree. It has been stated that the blast effect at the hydrogen bomb test in the fall of 1952 was about 150 times as powerful as for a Japan bomb, and at the hydrogen bomb test on March 1, 1954 the blast effect was stated to have been about 750 times larger than for a Japan bomb.

Production and Costs

Production of uranium weapons can be divided into two stages: construction of the atomic charge proper and production of the fissionable material: plutonium or uranium 235. The construction problems are apparent from the above made description. A good impression of the production of fissionable material can be obtained by looking at the conditions in England, for which an account has been given in the survey "Britain's Atomic Factories" published in 1954. Fig. 5 shows the principal outlines of this production. Uranium is extracted from the uranium ore and is then converted along the left flow line into metallic uranium which goes to the reactors, where plutonium is produced and then separated by chemical method from the irradiated uranium. This plutonium can be used for atomic weapons or for certain types of power-producing reactors. A considerable complication is the great intensity of radioactive radiation during various stages of the process which necessitates remote control and extensive protective measures. Another fact to be pointed out is that specific requirements must be made on plutonium to permit its use in atomic weapons. In the reactors, Pu 239 is created from U 238 through absorbtion of one neutron. The thus created Pu 239 can also catch one neutron and be converted to Pu 240. The proportion of the latter isotope must, however, be kept at a low level in "weapon grade" plutonium which must be considered in the manufacture.

Along the right flow line the uranium is converted into uranium hexafluoride, which is subjected to a physical separation in gas diffusion plants through which a product is obtained with a higher proportion of uranium 235. If the uranium in the end product consists almost completely of uranium 235, it can, like plutonium, be utilized for atomic weapons or for peaceful purposes. The English, however, are said to have utilized the gas diffusion plant primarily to obtain a

partially enriched uranium product. It is used to correct the lowering of the uranium 235 proportion which the uranium in the process first mentioned received in the reactors, so that it will again be as high as in natural uranium.

Fig. 6 and 7 show two plutonium-producing reactors and a gas diffusion plant. Whatever method is employed for production of atomic weapons, with plutonium or with uranium 235 as fissionable material, large installations are required, particularly at the capacity the great powers have acquired. At a more moderate capacity, however, neither installations nor costs are discouragingly large. The price of a uranium bomb depends in part on the intended yield, i.e. the quantity of fissionable material included, and obviously in part on the size of the production. Information from the USA varies between ¼ million dollars per atomic charge but in this price no amortization of installation and development costs seems to be included.

Manufacture of hydrogen weapons comprises all problems belonging to a uranium charge as long as such a charge is used to initiate the high temperature. In addition, there is the production of the lithium 6 isotope, found in natural lithium in up to about 7 per cent. It is, however, considerably easier to separate than the uranium isotope 235. The cost for this process as well as for production of the heavy hydrogen may therefore be regarded as relatively modest. To this must be added the cost for the waste uranium which is part of the hydrogen weapon; it is about a thousand times cheaper per kilogram than the fissionable material, plutonium or uranium 235. In relation to the size of the area of destruction, the hydrogen bomb becomes much cheaper than the uranium bombs. This applies mainly to moderately large hydrogen bombs. For the very largest hydrogen bombs this gain decreases because the "surplus destruction" in the center of the damage area does not pay any dividend.

To get rid of the large amounts of radioactive fission products created by this type of hydrogen bomb, a design may be feasible where all or almost all release of energy originates from thermonuclear reactions. Thus, outer layer of natural uranium would exist in this type. It has been stated though, that this type bomb must become more expensive than the earlier mentioned type, because the material for the thermonuclear reactions cost more than the relatively cheap waste uranium.

For calculations on stock piles and production capacity of atomic charges in various countries we could begin with an estimate of the availability of fissionable material on the basis of various published data. The number of atomic charges obviously depends on what size they are. If we presume about 10 kilograms of fissionable material per charge we will find that the USA probably have considerably more than 10,000 atomic charges, the USSR several thousand, and England several hundred. In all countries where energy-producing reactors are put in operation, access to plutonium is thereby gained. This material

can be made useful for atomic weapons as well as for enriched reactors for production of energy. A large number of countries will thus face the opportunity during the next 10-year period to be able to manufacture atomic weapons if they so desire. As for hydrogen weapons we know that the USA and the USSR have access to such weapons and that England soon is likely to have them fully developed.

Effects

The atomic weapon must nowadays be regarded as a very flexible weapon. As shown above, it is possible to select between various sizes, both in regard to the amount of energy released and total weight, from light uranium weapons to powerful hydrogen bombs. It is possible to choose various heights of burst and in that way vary the effects that are desired. Finally, the design can be varied in such a way that certain effects become more prominent.

The release of energy at the explosion of an atomic bomb is difficult to measure directly. The effect of an atomic weapon is therefore usually defined by stating the amount of TNT that in a charge will give the same blast effect. This amount is generally given in kilotons (KT) = 1000 metric tons. Following examples may be cited on the effect of various atomic weapons.

Japan bombs 1945	20 KT	
Light atomic weapons	1 to 2-40 "	
Powerful uranium bomb (Eisenhower)	500 "	
US hydrogen bomb, fall of 1952	3,000 "	
" " " , March 1, 1954	15,000 "	
Russian hydrogen bomb, November 1955	1,000 "	?

A 20-Kt atomic bomb develops an amount of energy equal to a complete fission of one kilogram of uranium 235. Expressed in various units we then obtain the following values: 20,000 metric tons of TNT, 2×10^{13} calories, 8.4×10^{20} erg, 2.3×10^{7} KWh. Despite the fact that enormous amounts of energy are developed at an atomic bomb explosion, they are small in comparison with those existing in nature. A strong earthquake thus equals millions of atomic bombs, and already in a powerful hurricane the amounts involved equal a number of atomic bomb explosions.

At an atomic bomb explosion an almost instantaneous release of the above mentioned large amounts of energy takes place, with the result that the temperature rises rapidly to several tens of millions degrees Centigrade and that the pressure increases to extremely high values. Without going into details on how the explosion develops, only the following information will be presented here. Almost at the same moment as the explosion has been released, a rapidly expanding fireball becomes visible. From this ball, heat radiation is transmitted and a powerful shock wave develops. In Fig. 8 an illustration is shown of the fireball during its expansion. At the moment of explosion,

radioactive radiation is also generated, mainly neutrons and gamma radiation. In addition, strongly radioactive fission products are created which at a low-level explosion will cause a radioactive covering in large areas. The effect of an atomic bomb explosion thus depends principally on three or perhaps rather four different causes: shock wave, heat radiation, and radioactive radiation which can be divided into initial radiation and remaining radioactivity.

The effect of a Japan bomb is well known and the effects of other atomic weapons are calculated from this starting point by using certain scaling laws. In this method it is assumed, however, that the energy developed is distributed on the various forms of energy in the same way as with the Japan bombs. For these bombs about one third of the energy went to heat radiation, about 10 per cent to the radioactive radiation, and the remainder to other forms, mainly the air shock wave. Even if the bomb type may vary and the above condition does not apply, it is still possible, through the method described, to reach a good conclusion on how the size of the damage area varies with yield of the bomb. From the definition of the bomb yield follows that the radius for a certain pressure effect is proportionate to the cube root of the released energy. As for heat radiation and radioactive radiation, however, the scaling relationship is more complicated because we must consider the fact that the source of radiation is not concentrated in one point and also absorbtion and dispersion in the atmosphere. Thus we will find that the radius for heat effect decreases considerably as humidity in the atmosphere increases. If this radius for a 20-KT bomb is 1 when visibility is 20 kilometers, it becomes two-thirds and 0.4 when visibility decreases to 10 and 5 kilometers respectively.

In Table 1 the outer limits of the radii from ground zero, i.e. the spot on the ground straight under the explosion center, are given for a few typical damage effects from atomic bombs of various yields. The Japan bomb has been designated as the nominal atomic bomb. In addition, a uranium bomb with 10 times larger blast effect has been included and two hydrogen bombs 100 and 1000 times more powerful respectively. Burst heights have been selected in such a way as to obtain damage to material over as large an area as possible. This occurs for the nominal atomic bomb at a burst height of 600 meters and for a 10 times more powerful bomb at 1,300 meters. For the hydrogen bomb alternatives this optimum height explosion height is not so defined and, besides, it does not play a very important role because the destruction area still is so tremendously large.

TABLE 1

RADII IN KILOMETERS FOR SOME TYPICAL DAMAGE EFFECTS FROM BOMBS
OF VARIOUS YIELDS
GOOD VISIBILITY 15 KILOMETERS

	Nominal	x 10	x 100	x 1000
Bomb yield in thousands of metric tons of TNT	20	200	2,000	20,000
Height of burst in meters	600	1,300	(3,000)	(6,000)
Brick house with concrete beams totally razed, concrete house heavily damaged but reparable	1.2	2.5	6	12
Brick house with wooden beams and frame house totally razed	1.6	3.5	8	16
Light damage to structures	3	6.5	14	30
Wood and fabric ignited	1.7	4	8	15
Heavy burns to unprotected skin	2.3	5	10	20
Light burns to unprotected skin	3.2	7	15	30
Radioactive effects, 50 per cent mortality, initial radiation	1.1	1.5	2	3-4

Damage areas for atomic bombs of various yields over Stockholm are shown in Fig. 9. If a 20-KT atomic bomb explodes at a great height over the Parliament building, the resulting damage is such that repair of brick houses would be impractical in the Old City, half of Kungsholmen, all of Norrmalm with adjoining portions of Vasastaden, half of Ostermalm, and almost half of Sodermalm.

Table 2 shows how the effects vary with the height of burst.

TABLE 2

Height of burst	Shock wave	Heat radiation	Radioactive initial radiation	Induced radioactivity
Great height	a	b	c	-
Ground	3/4 a	3/4 b	c	+++
Underground	1/2 a	-	-	++
Underwater	1/2 a	-	-	++

It should be noted that no induced radioactivity of any significance results from high burst. Only when the burst height is so low that the fireball touches the ground at the explosion, will this effect be of any significance. At the ground or underground burst the effect is extremely serious, particularly from powerful atomic bombs.

Table 3 shows the time for various effects of a 20-KT atomic bomb. For more powerful bombs, these times become much longer; largely they are proportionate to the cube root of the released energy.

TABLE 3

Heat radiation	Mostly within 0.3 sec. No burns after 0.6 sec.
Radioactive initial radiation	Half within 1 sec. Completely gone after 1 min.
Shock wave	Lasts a few sec. Reaches 1,000 m. after 1.5 sec. " 2,000 " " 4 " " 3,000 " " 7 "

The radiation intensity from the radioactive fission products created at the explosion decreases rapidly at first but then gradually slower. This is shown in Table 4 which shows the decrease in activity for a 20-KT bomb (1 MC = 1 million Curie).

TABLE 4

Time after explosion	Activity in MC
1 minute	$8.2 \cdot 10^5$
1 hour	$6.0 \cdot 10^3$
24 hours	133
1 week	13
1 month	2.3
1 year	0.11
10 years	$0.8 \cdot 10^{-2}$
100 years	$0.6 \cdot 10^{-3}$

In Fig. 10 a simplified sketch is shown on how the radioactive particles created by an atomic explosion are spread. To the left, conditions under high burst are illustrated. The finely pulverized atomic bomb material will then be the single carrier of the radioactive fission products. The light particles are carried up to great heights by air currents, for uranium weapons up to about 10 kilometers, for hydrogen weapons as far up as to about 40 kilometers. For atomic weapons under 1000 KT yield, the larger portion of the dust stays in the troposphere. It is swept away by the winds and carried far away but generally remains at the latitude on which the explosion took place. Within the course of one or two months, the greater portion of the dust can be considered to have descended to the surface of the Earth. Atomic weapons with a larger yield, however, i.e. more than one MT, push the greater portion of their radioactivity into the stratosphere.

High-altitude winds then disperse this dust over the entire globe. A long time elapses before it is deposited on Earth. It is believed that of the radioactive dust existing in the stratosphere only 10 to 20 per cent will descend to the ground annually. It has then spread to very large volumes and at the same time the intensity has decreased considerably because of the time elapsed. It should be pointed out that at explosions of those atomic charges largely based on fission of heavy atomic nuclei, the amount of radioactivity created is approximately proportionate to the yield of the atomic weapon. Future hydrogen weapons of a different design, however, may produce considerably smaller amounts of long-life radioactivity.

Also in our country we have been able, through the use of suitable measuring instruments and measuring methods, to measure such radioactivity originating from various atomic weapons tests, the greater portion originating from tests of hydrogen weapons. Systematic measurements of this type are taking place since several years. Figure 11 shows the result of measurements undertaken by the Defense Research Establishment on the radioactivity in the Stockholm area from various atomic weapons tests. However, those quantities of radioactive dust that have been deposited here so far have been harmless since the radiation dosages we receive in this way are small compared to what we receive in other ways, from natural sources of radiation, x-rays, etc. The largest risk is connected with the long-life isotope strontium 90, having a half-life of 28 years. Measurements show that for this isotope the level reached so far is at one or a few per cent of the very conservatively calculated permissible level. However, it is of the greatest importance that we continuously monitor the radioactive fallout over our country and thereby pay special attention to strontium.

To the right in Fig. 11 are illustrated the conditions at a burst on the ground surface. We will then have a considerable cratering effect with a radius of about 100 meters for a 20-KT bomb and of about one kilometer for a powerful hydrogen bomb. All the displaced material will then be contaminated with radioactivity. The larger particles are thrown directly out in the surrounding area and soon descend to the ground. Thus is formed what is generally called the radioactive close-in covering, the extension of which largely coincides with the area of material damage except leeward (sic!), where the extent is considerably smaller. Particles not quite as large are carried by the air current upwards as far as a height between 10 and 40 kilometers. A great portion of the material carried up to these heights consists of particles so large that they fairly soon descend in the direction of the wind in an elongated area, generally called the distant fallout. Within this area, great intensities prevail in the central portions, which is indirectly shown in the sketch in Fig. 12, illustrating the extension of the distant fallout at the American test of a 15-MT hydrogen bomb on March 1, 1954. It should be emphasized,

however, that great variations occur, both in size and shape of the areas that become covered with residual radioactivity, above all because of different wind velocities but also because of different character of the soil, other meteorological conditions, etc. The close-in and distant fallout at a ground burst may represent about 80 per cent of the total activity. The remainder, with fine dust as a carrier, has been swept away by high-altitude winds, as at a high burst, for a more global dispersion.

As an example on the effect of a low-burst hydrogen-bomb explosion we may consider a 15,000-KT hydrogen bomb exploding over Stockholm during easterly high-altitude winds of 10 meters per second. -- It should be emphasized, however, that westerly high-altitude winds of a considerably greater force are the most common winds over our country. -- The damage area for material has a radius of about 20 kilometers (cf. Table 1). Within this area all of Greater Stockholm is contained and lesser effects can be expected even outside. The area covered by dangerous radioactivity extends over Eskilstuna, Orebro, Karlstad, and to the Varmland forests. Vasteras, Katrineholm, and Hallsberg would probably be situated in the fringes of the area. At Eskilstuna, the radioactive dust begins to fall $2\frac{1}{2}$ hours after the explosion, at Orebro after $4\frac{1}{2}$ hours, and at Karlstad after 7 hours. Anybody staying in the open during the first 36 hours after the beginning of the fallout would receive a dosage of 2,300 r at Orebro and 600 r at Karlstad [see note]. Staying in the fallout area without receiving a larger dose than 100 r is possible at Orebro after 36 hours and at Karlstad immediately after the fallout. (Note: A dose of 450 Roentgen is estimated, under these conditions, to possibly result in 50 per cent mortality.)

The radioactive fallout is a very troublesome complication when we concern ourselves with rescue operations etc. in a very large portion of the area of material damage. Distant fallout constitutes a serious hazard from the powerful hydrogen bombs, whereas the hazard from light atomic weapons is only of lesser significance. Because of the risks from the powerful atomic weapons, the United States have worked out a system for continuous high-altitude wind prediction which is distributed to civil defense units, particularly at probable hydrogen bomb targets. When a hydrogen bomb has exploded, it will then be possible to transmit an immediate alert to the estimated fallout area. A certain evacuation may then be possible and, in addition, shelter may be sought in basements and substantial houses. Here a summary follows of the intensity in various types of houses compared to outside conditions in a completely level area.

Open terrain	85-95 %
Simple wooden hut	50-65 %
Frame house, upper floor	50 %
" " , lower "	35 %
" " , basement	5-10 %

Brick house, lower floor	15	%
" " , basement	2-5	%
" " , shelter in basement	0.1	%

As a general rule, 50 to 80 centimeters of earth, 65 centimeters of brick, or 40 centimeters of concrete reduce the radiation capacity to one thousandth. Behind such a shield it generally would not be dangerous to stay for weeks or even months. Within the area of heaviest fallout it may be necessary to remain under cover during up to a week before evacuation can take place. It is then obviously important that the cover is safe, but in addition there is a great problem: the food supply during this period.

Another serious problem is the long-range effects of radioactive fallout. In the central, heavily contaminated area it would seem to be impossible to settle for about a year. Within all of the fallout area mentioned above, and far outside it, there may be a risk for several years that the vegetation will absorb radioactivity from the soil. The greatest hazards will then occur through the dispersion of the radioactive elements from the crop to the grazing cattle and thence via milk to humans. The ecological problems involved are, however, remarkably inadequately clarified.

The above hints show that much can be done to reduce the damage effects of an atomic bomb explosion. Atomic weapons create a terrible destruction, but through preparatory measures, a suitably built up civil defense organization, and correct actions by the individual, tens of thousands of lives can be saved. In this case it is impossible to differentiate between civilian and military forces. They must cooperate closely toward a common goal. It is important that the organization for the limiting of damage is built up to cope mainly with those methods of attack and types of weapons most likely to be employed against us. But it is also important that the protective measures within the framework of our resources are balanced so that the protection is uniformly strong and leaves no gaps. Improvised measures in the organization would have a rather small chance of succeeding. Careful preparations are required in this field, but the initiative of the individual still is of very great importance, particularly during the first hours after an atomic explosion.

The shelters are, as explained above, a particularly valuable asset at residual radioactivity. The same is true about their value against the immediate effects of an atomic bomb explosion. Here it is the shock wave that determines the limit-establishing protective factor. Our rock shelters generally would suffice except at a surface burst straight above the shelter. But such a hit requires precision bombing and therefore seems to be relatively improbable. Even our conventional shelters are extremely valuable. It is true that they do not offer adequate protection in the center of the damage area, but they constitute a very valuable asset in the outskirts of this area and they

may reduce the number of casualties to a high degree, and it is of course here we have the large areas. Fig. 13 shows a few simple shelters which saved a number of Japanese from the effects of the atomic bomb.

An important problem is the organizing of a purposeful monitoring service of radioactive radiation. As we all know, we cannot register this radiation with our senses, a fact which makes this service a necessary must. The following measuring problems and need for instruments exist.

Burst point indicators to determine the location of the point of burst so that we will quickly get information, particularly on the height of the burst. This might be combined with a meter of bomb yield.

Mapping of the radioactive area by intensity meter from airplane or car, or hand-carried by the meter operators. Attention should be paid to the organizational problems, particularly when large areas are involved.

Dosimeters for personnel dispatched into the area so that it can be checked that they are not exposed to a dangerous dose.

All persons emerging from the fallout area must be checked for possible radioactive fallout on clothing, skin, belongings, etc. for which purpose a sensitive low-intensity meter would be used.

Knowledge of the initial dose is desirable for sorting of the casualties with consideration to the need, or absence of need, of beginning medical treatment. It is therefore desirable that a large number of individuals carry a special initial dosimeter. Reading of these instruments should take place centrally at those installations where individuals from the damaged area are being collected. Medical units will face very great problems at an attack with atomic weapons. Burns, contusions, etc. dominate which does not mean that the radioactive injuries can be disregarded. The greatest number of casualties will occur during atomic bomb attacks against our cities. The simultaneous occurrence of damage over a large area would have the result that the local medical resources would be inadequate. Thus a heavy burden would be imposed on the medical organization within a very large area.

Concluding Remark

The discovery of a new source of energy has always entailed a development for good or for evil, and the atomic energy does not constitute any exception in this respect. Let us hope that humanity will recover its senses and let the good prevail over the evil.

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FIGURE APPENDIX

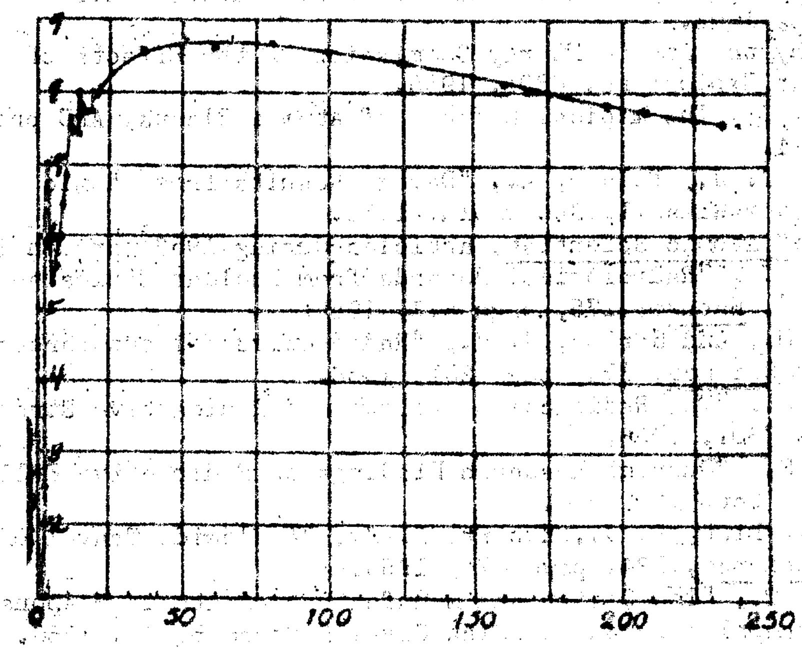
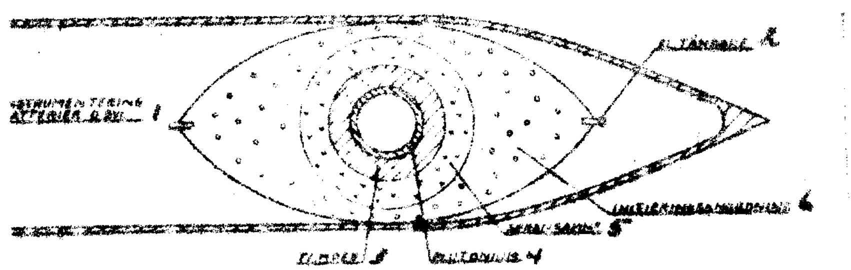


Figure 1. Cohesive energy per nucleon for various values on mass.



1. Instruments, batteries, etc.
2. Electric blasting cap
3. Tamper
4. Plutonium
5. Explosives
6. Initiating arrangement

Figure 2. Principal design of uranium bomb.

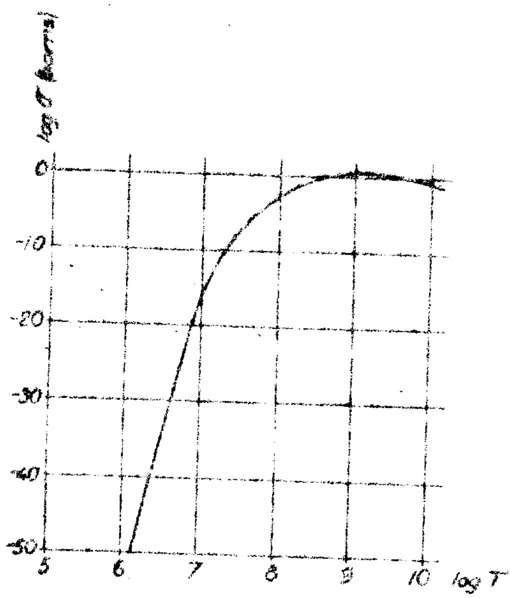
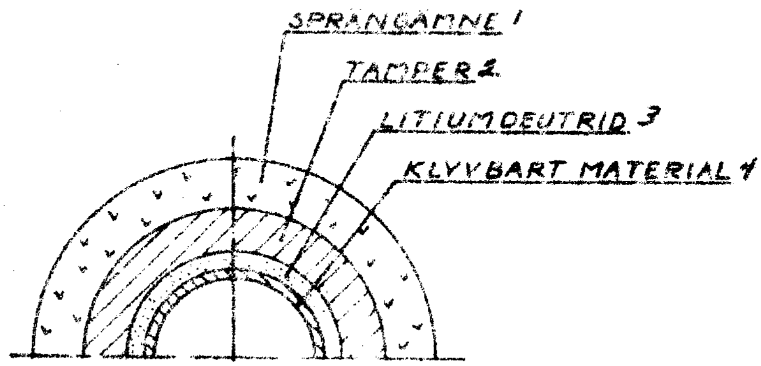


Figure 3. Variation in average effect with the temperature for the reaction $T + D \rightarrow He^4 + n$. 1 barn = 10^{-24} cm^2.



1. Explosives
2. Tamper
3. Litium deutride
4. Fissionable material

Figure 4. Principal design of hydrogen bomb.

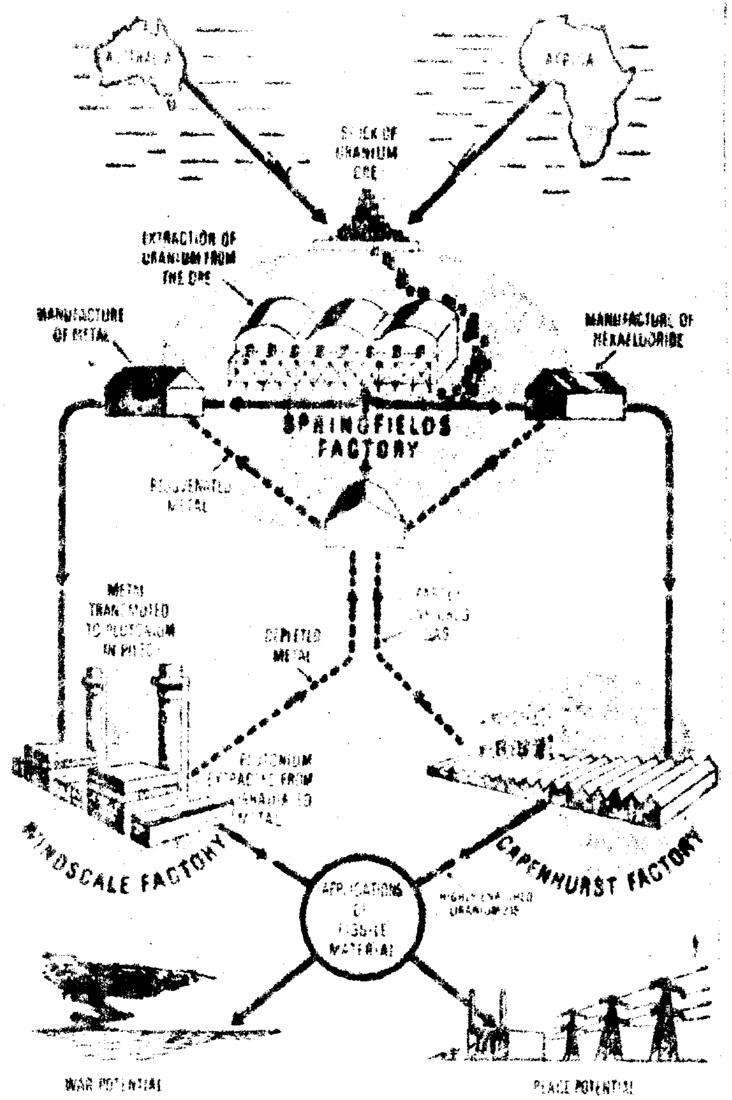


Figure 5. Basic outline of the British manufacture of fissionable material.

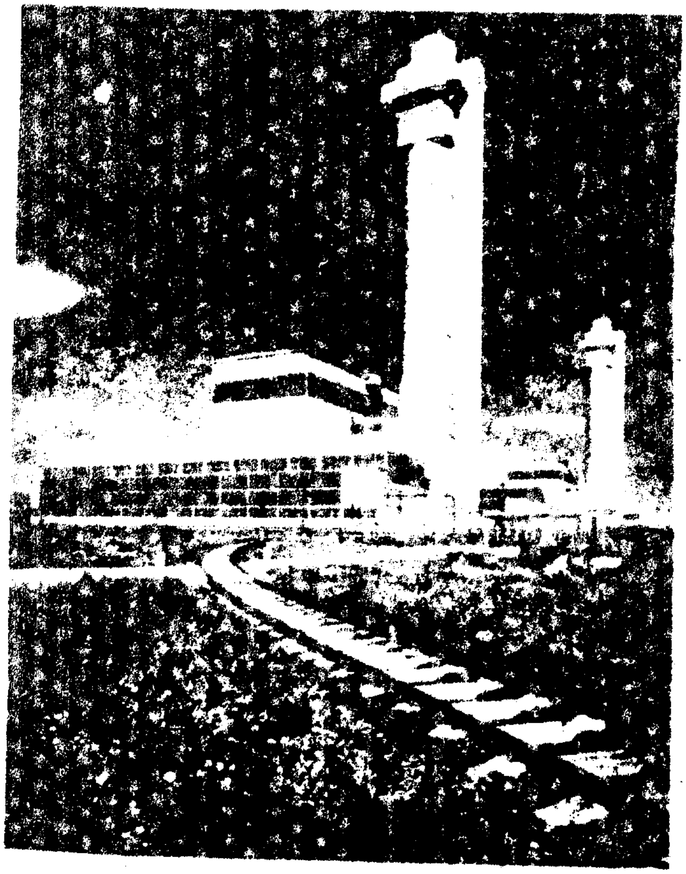


Figure 6. The British plutonium-producing reactors at Windscale.
Height of chimneys is 125 meters.

Figure 7. The American gas diffusion installation at Oak Ridge. The main installation at the center of the picture extends to 360 by 750 m^2 (sic).

Figure 8. Fireball at the first atomic bomb explosion at Alamogordo. The shockwave front has just separated from the fireball. A dust cloud is stirred up at the ground. Just above the cloud a phenomenon is visible which is a result of interference between the primary shockwave and the one reflected against the ground.

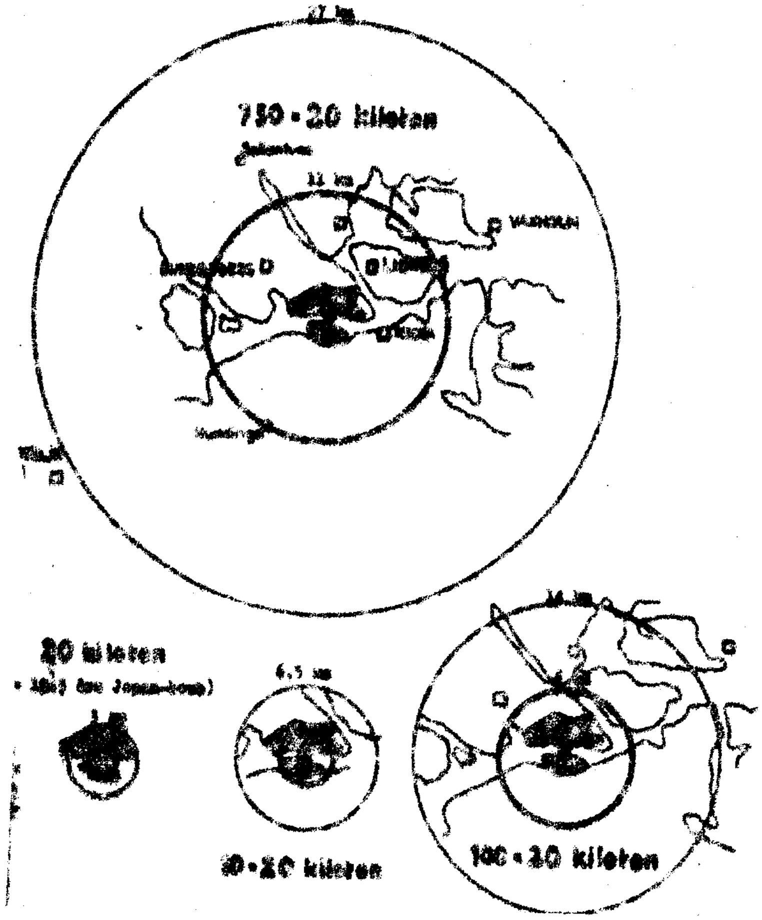


Figure 9. Damage areas over Stockholm. Effect radii of high burst at 20; 200; 2,000; and 15,000-KT atomic weapons over Stockholm. The inner circle denotes the outer limit for total razing of brick houses with concrete beams. The outer circle is the limit of damage to unprotected persons and limit for light damage to structures.

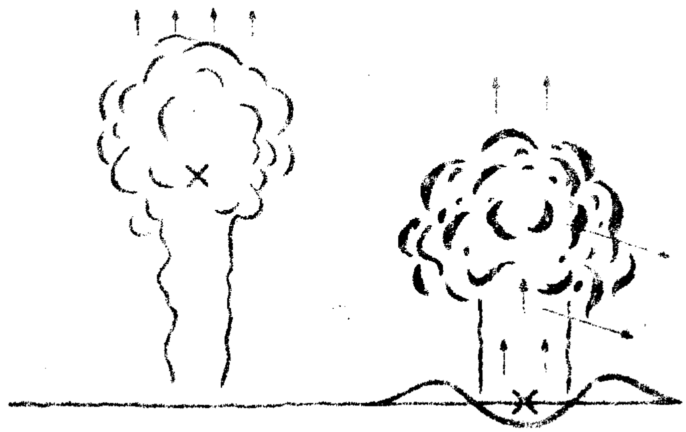


Figure 10. Basic principles of the dispersion of radioactivity at high and low burst.

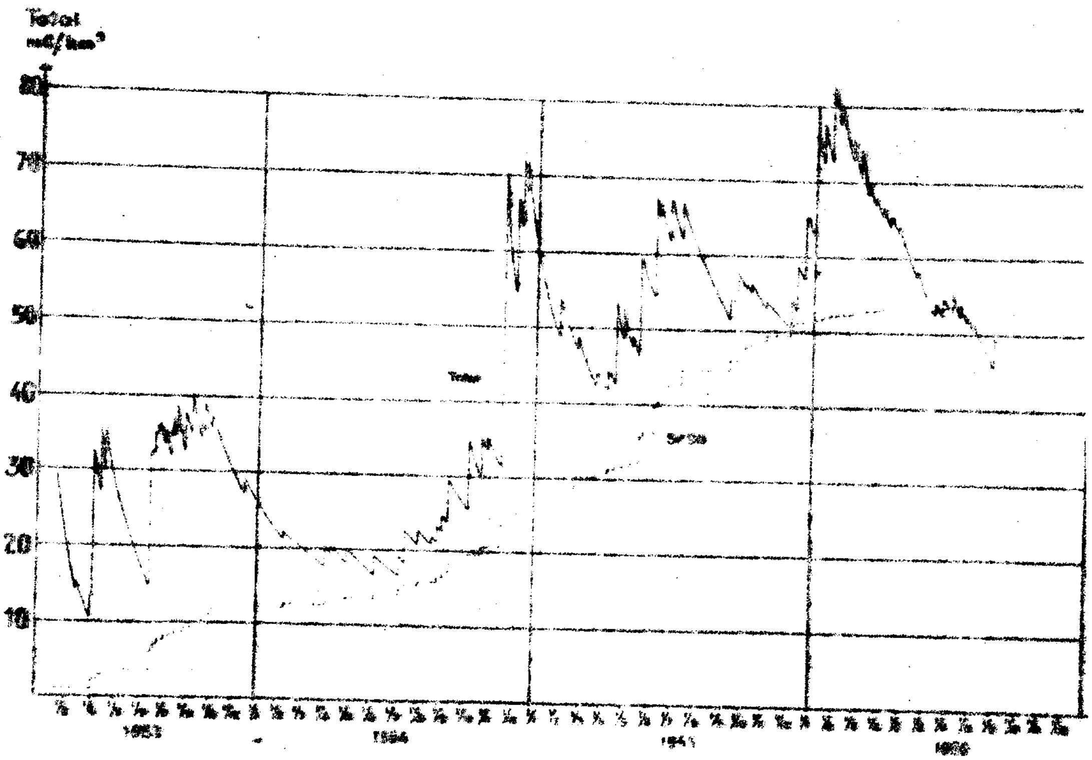
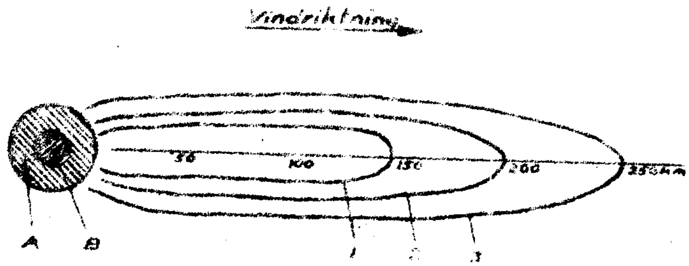


Figure 11. Radioactive fallout in the Stockholm area May 1, 1953 through September 1, 1956. The solid line shows the total radioactivity (left scale). Each jump in the curve is matched by precipitation causing an increase in activity. The dashed line shows the variation of Sr 90 (right scale).



Wind direction

Figure 12. Example of radioactive distant fallout from low burst of a 15,000-kiloton hydrogen bomb.

A and B: damage area for light and heavy damage to material. The curves 1 through 3 denote the limits where it would be possible to stay unprotected during 4 hours from 48 hours, 36 hours, or immediately after the explosion, respectively, without receiving a radiation dose exceeding 100 roentgen.

Figure 13. Simple shelters near ground zero at Nagasaki which protected persons within them from all effects of the atomic bomb.

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